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Effect of Chemical and Microbial Amendment on Phosphorus Runoff from Composted Poultry Litter

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ABSTRACT

Environmental impacts of composting poultry litter with chemical amendments at the field scale have not been well quantified. The objectives of this study were to measure (i) P runoff and (ii) forage yield and N uptake from small plots fertilized with composted and fresh poultry litter. Two composting studies, aerated using mechanical turning, were conducted in consecutive years. Composted litter was collected at the completion of each study for use in runoff studies. Treatments in runoff studies included an unfertilized control, fresh (uncomposted) poultry litter, and litter composted with no amendment, H_3PO_4, alum, or a microbial mixture. An additional treatment, litter composted with alum plus the microbial mixture, was evaluated during the first year. Fertilizer treatments were applied at rates equivalent to 8.96 Mg ha^{-1} and rainfall simulators were used to produce a 5 cm h^{-1} storm event. Composted poultry litter, regardless of treatment, had higher total P concentrations than fresh poultry litter. Composting poultry litter resulted in reductions of N/P ratios by as much as 51%. Soluble reactive P concentrations were lowest in alum-treated compost, which reduced soluble P concentrations in runoff water by as much as 84%. Forage yields and N uptake were greatest from plots fertilized with fresh poultry litter. Composting poultry litter without the addition of C sources can increase P concentrations in the end product and surface runoff. This study also indicated that increased rates of composted poultry litter would be required to meet equivalent N rates supplied by fresh poultry litter.

Use and disposal of animal waste has become an issue of environmental concern as the structure of animal agriculture has shifted toward fewer but larger operations along with an increase in the percentage of animals in confinement (Kellogg et al., 2000). Poultry production is a growing industry that represents a substantial portion of livestock operations within the USA (National Agricultural Statistics Service, 2005). From 1982 to 1997, the number of livestock operations with poultry decreased by 62%, whereas the number of poultry animal units increased by 52% (Kellogg et al., 2000). Long-term applications of poultry litter based on crop N requirements can lead to P levels that exceed the amount typically required by the crop. An accumulation of soil P or land application of poultry litter in hydrologically sensitive areas increases the risk for P movement to the environment through surface runoff (Sharpley, 1995). The NRCS now implements P-based management strategies to control P losses to the environment (Sharpley et al., 2003).

Composting is a practice that can reduce the amount of animal manure concentrated in local areas. Composting manure has been shown to reduce total mass by as much as 50% (Dao, 1999). Composting animal manures produces a stabilized product that reduces odors, reduces weight and volume, and results in pathogen kill (Sweeten, 1988); however, N loss during composting of animal manures can be substantial (Kirchmann and Witter, 1989; Henry and White, 1993; Kithome et al., 1999; DeLaune et al., 2004b).

Unlike N, P is retained during the composting process. Due to P retention and material mass loss during the composting process, P concentrations may increase in composted manure. In this case, N/P ratios decrease and P applications of composted manure are higher than uncomposted manure when applied at equivalent rates. Studies have reported a decrease in P concentrations in composted animal manures and subsequent runoff water with the addition of low-P bulking agents at the beginning of the composting process (Sharpley and Moyer, 2000; Vadas et al., 2004). Vervoort et al. (1998) concluded that composting broiler litter without the addition of C created more stable components and was an effective way to control NO_3 leaching, but was not as effective in controlling soluble P in surface runoff.

Controlling soluble P in the animal manures can have significant impacts on P losses in surface runoff as the majority of surface runoff P from pasture systems is of the soluble form (Edwards and Daniel, 1993). Alum additions to poultry litter decrease water-soluble P concentrations in the litter (Moore and Miller, 1994; Sims and Luka-McCafferty, 2002; DeLaune et al., 2004a). Amending poultry litter with alum also significantly reduces P concentrations in surface runoff under simulated rainfall (Shreve et al., 1995; DeLaune et al., 2004a). Moore et al. (2000) reported that soluble P concentrations in runoff from pastures fertilized with alum-treated litter averaged 73% lower than that from normal litter during a 3-yr period. Aluminum and Fe amendments to composting poultry litter with bulking agents have been shown to reduce soluble P concentrations in the composting mixture (Dao et al., 2001; Vadas et al., 2004).

Chemical amendments have been shown to decrease P availability in fresh poultry litter and poultry litter composts; however, no studies have yet reported the effects on P runoff and forage yield of amendments to field-scale composting of poultry litter without bulking agents. The objectives of this study were to measure (i) P

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Abbreviations: SRP, soluble reactive phosphorus; TP, total phosphorus.

runoff and (ii) forage yield and N uptake from small plots fertilized with composted and fresh poultry litter.

MATERIALS AND METHODS

Composting Procedure

Composting trials were conducted in two consecutive years evaluating NH_3 emissions from composting poultry litter (DeLaune et al., 2004b). Poultry litter was windrowed each year into rows weighing ~3600 kg. Various rates of alum, H_3PO_4, and a microbial mixture were added to selected windrows at the beginning of the composting process without additional C sources or bulking agents. Mechanical turning was used to aerate the windrows during the 68-d composting process in Year 1 and 93-d composting process in Year 2. Complete details of the composting studies and procedures are reported in DeLaune et al. (2004b).

Runoff Studies

After each composting trial, runoff studies were conducted on small runoff plots (1.52 by 6.10 m, with 5% slope) cropped with tall fescue (*Festucca arundinacea* Schreb.) at the Main Agricultural Research Station of the University of Arkansas on a Captina silt loam (fine-silty, siliceous, mesic Typic Fragiudult). A portion of the poultry litter that was composted each year was collected and frozen before the composting process. The frozen litter was used to represent uncomposted poultry litter, which will be referred to as *fresh poultry litter*. Representative samples of composted poultry litter were collected at the end of each trial for use in runoff studies.

There were seven treatments the first year, including an unfertilized control, fresh poultry litter, and poultry litter composted with no amendment (normal compost), 10% alum, 2% H_3PO_4, a microbial mixture, or 5% alum plus a microbial mixture. Six treatments were evaluated the second year, consisting of an unfertilized control, fresh poultry litter, and poultry litter composted with no amendment, 7% alum, 1.5% H_3PO_4, or a microbial mixture. Each year, treatments were assigned to plots in a randomized complete block design with four replications. All fertilizer treatments were applied at rates equivalent to 8.96 Mg ha^{-1} (fresh-weight basis) immediately before the first rainfall event.

Before fertilizer application, 10 soil cores (0–5 cm) were taken from each plot and composited for Mehlich 3 P analysis. Mehlich 3 P was analyzed using an autoanalyzer after extracting 2 g of soil with 14 mL of Mehlich 3 solution (Mehlich, 1984). Mean Mehlich 3 P concentrations were 160 and 276 mg P kg^{-1} for Years 1 and 2, respectively. Subsamples from each fertilizer treatment were also collected for analysis. Twenty grams of poultry litter from each sample was placed in a 250-mL polycarbonate centrifuge tube and extracted with 200 mL of deionized water for 2 h on a mechanical shaker for soluble P analysis (Self-Davis et al., 2000). Aliquots from centrifuged samples were filtered through a 0.45-μm membrane and acidified to pH 2 with HCl. Soluble reactive P was determined colorimetrically using the automated ascorbic reduction method (American Public Health Association, 1998). Total P was determined by digesting oven-dried (60°C) litter with HNO_3, and analyzing the digested sample using ICP (inductively coupled plasma; Zarcinas et al., 1987). Total N was determined on a LECO-CNS elemental analyzer (LECO Corp., St. Joseph, MI).

Rainfall simulators were used to provide a 5 cm h^{-1} storm sufficient in length to produce 30 min of continuous runoff. Rainfall was applied immediately after fertilizer application the first year and 1 and 8 d after fertilizer application the second year. Runoff samples were collected at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 min after initial runoff was observed. The six samples were composited based on flow rates at the time of sampling. Composited runoff water samples from each plot were filtered through a 0.45-μm membrane and acidified to pH 2 with concentrated HCl. Soluble reactive P concentrations were determined colorimetrically on filtered, acidified samples using the automated ascorbic acid reduction method (American Public Health Association, 1998). Unfiltered, acidified samples were analyzed for total P with a Spectro Model D ICP (Spectro Analytical Instruments, Kleve, Germany) after digestion with HNO_3 according to APHA Method 3030E (American Public Health Association, 1998).

Forage Study

Rainfall simulation plots were mowed to a height of 10 cm 1 d before the application of any treatments each year. Thereafter, each plot was mowed with a bagger-mower to a height of 10 cm every 2 wk for 6 wk after the initial fertilizer application. Forage wet weights were determined and subsamples were taken for moisture content and N analysis. All forage yields were corrected to a dry-weight basis. Dried forage samples were ground using a Wiley mill to pass a 2-mm screen. Total N in the forage tissue was determined using a LECO CNS elemental analyzer (LECO Corp.).

Analysis of variance was used to determine significant treatment effects (SAS Institute, 1990). When significance was indicated, means were separated using Fisher's protected LSD ($P < 0.05$).

RESULTS AND DISCUSSION

Litter Phosphorus

Total P concentrations were higher for poultry litter that had been composted than for fresh poultry litter (Table 1). Excluding H_3PO_4–treated compost, the mean total P concentration of composted poultry litters was 22% higher in Year 1 and 32% higher in Year 2 compared with fresh poultry litter (starting compost material). These results are similar to those reported by Vadas et al. (2004), who found a 20% increase in total P concentrations in the final compost product. As expected, H_3PO_4–treated compost had the highest total P concentration among all litters (Table 1). Total P concentration in H_3PO_4–treated compost was 43 and 49% higher than fresh poultry litter in Years 1 and 2, respectively. A greater increase of total P concentration in the second year can be attributed to a longer composting process (68 vs. 93 d), resulting in a greater mass loss (DeLaune et al., 2004b).

Alum-treated compost had the lowest SRP (soluble reactive phosphorus) concentration among all treatments (Table 1). Concentrations of SRP in alum-treated compost were 93% lower in Year 1 and 85% lower in Year 2 than fresh poultry litter (Table 1). Similar to other studies (Vadas et al., 2004; Dao et al., 2001), Al amendments had little effect on total P concentrations, but substantially reduced levels of SRP in the final compost product.

All other composts had higher SRP values than fresh poultry litter (Table 1). Normal compost had SRP concentrations 24% higher in the first year and 44%

Table 1. Concentrations of TP (total P) and SRP (soluble reactive P), application rates of TP, SRP, and N, and N/P and N/SRP ratios of fresh and composted poultry litter, with and without amendments.

Treatment	TP	SRP	TP applied	SRP applied	N applied	N/P	N/SRP
	g kg^{-1}		kg ha^{-1}				
Year 1							
Fresh litter	25.7	1.24	163	7.87	312	1.91	39.6
Alum	30.6	0.095	154	0.48	229	1.48	476
Alum + microbial	33.4	0.31	173	1.62	219	1.26	135
H_3PO_4	44.8	2.29	245	12.5	230	0.94	18.4
Normal	34.5	1.63	208	9.85	219	1.05	22.2
Microbial	33.5	1.34	210	8.42	219	1.04	26.0
Year 2							
Fresh litter	16.4	1.42	119	10.3	345	2.90	33.5
Alum	24.8	0.21	157	1.31	300	1.91	229
H_3PO_4	32.1	6.22	204	39.5	306	1.50	7.74
Normal	23.6	2.52	160	16.9	288	1.80	17.0
Microbial	23.8	2.14	162	14.7	282	1.74	19.2

higher in the second year than fresh poultry litter. Other studies have reported lower water-soluble P in composted manures (Vadas et al., 2004; Sharpley and Moyer, 2000); however, these reported reductions were due to dilution with bulking agents that were added before the composting process. Results from this study indicate that, without bulking agent additions, SRP concentrations increase due to the composting process. It should be noted that most growers do not normally add bulking agents when composting poultry litter or manure.

Nitrogen/Phosphorus Ratio

Concerns arise from the risk of elevated P levels in both soil and surface runoff water as a result of land application of manures. These concerns are warranted due to the imbalance of N and P applications rates, with P applications generally exceeding agronomic P requirements when litter is applied based on N. Results from analyses of composted poultry litter showed increased P concentrations. DeLaune et al. (2004b) also showed substantial losses of N from composted poultry litters. As seen in Table 1, N/P ratios of composted litter were reduced by as much as 51%. All of the composted litters had lower N/P ratios than fresh poultry litter. DeLaune et al. (2004b) reported that alum-treated litter greatly reduced NH_3 loss, hence more N was retained compared with normal compost and microbial-treated compost. While H_3PO_4 additions also reduced N emissions, P concentrations were greatly increased.

Perhaps of more importance, N/SRP ratios were greatly affected among composted litters. Soluble P concentrations in runoff water have been shown to be highly correlated with the solubility of the fertilizer source, with P concentrations in runoff water increasing with increasing levels of soluble P in the source (Kleinman et al., 2002; DeLaune et al., 2004a). As with N/P ratios, composted litters generally had lower N/SRP ratios than fresh poultry litter. The exception was alum-treated compost, which had the greatest N/SRP ratios among all other fertilizer treatments (Table 1). The N/SRP ratios of alum-treated compost were 476 in Year 1 and 229 in Year 2 compared with 22 and 17 for normal compost in Years 1 and 2, respectively. Dao (1999) also found that alum rates substantially widened N/SRP ratios of both stockpiled and composted cattle manure. The decrease of N/P ratios in composted litter warrants investigation of the risk of composting on P runoff, especially if compost applications must be increased to meet N requirements.

Runoff Study

Year 1

Analysis of runoff water showed that SRP concentrations were significantly lower from plots fertilized with alum-treated compost than all other fertilizer treatments and not significantly different than the unfertilized control (Fig. 1). This was expected since alum-treated compost contained the lowest SRP concentrations and lowest P application rates (Table 1). Alum additions to microbial-treated compost significantly reduced total P and SRP concentrations in runoff water compared with compost treated with the microbial mixture alone (Fig. 1).

Although not significantly higher, SRP and total P concentrations in runoff water were highest from microbial-treated compost (Fig. 1). These results were not expected, since SRP application rates were not highest with microbial-treated compost (Table 1). We had hypothesized that H_3PO_4–treated compost would result in the highest P concentrations in runoff water since it had the

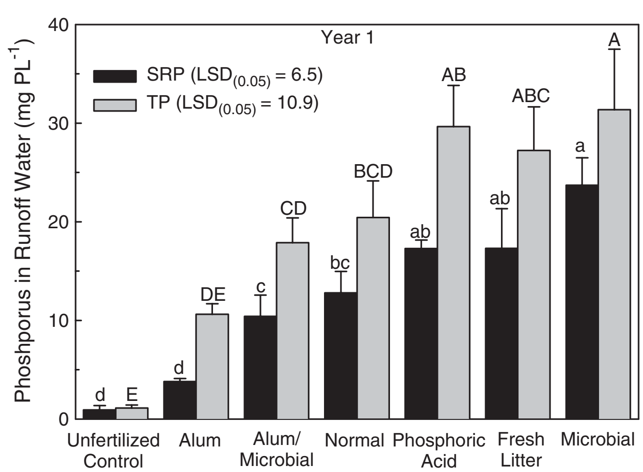

Fig. 1. Concentrations of SRP (soluble reactive P) and TP (total P) in runoff water from plots fertilized with fresh and composted poultry litter, with and without amendments, 1 d after application in the first year of the study.

highest SRP content. Although studies have shown increasing P losses with increasing SRP application rates, this trend was not observed during the first year. Phosphorus from composted manures has been shown to be as available as P in uncomposted poultry litter (Preusch et al., 2002; Sikora and Enkiri, 2003, 2005). Preusch et al. (2002) suggested that compost maturity may affect extractable P concentrations when added to soils. Although compost maturity was not determined in this study, it may have been a factor in P stability during the shorter first-year composting process.

Total P concentrations in runoff water followed similar trends to SRP (Fig. 1). Alum treatments resulted in numerically lower TP (total phosphorus) concentrations in runoff water. Results from the first year do not provide evidence that the amount of P applied via composted manures can be directly correlated to P runoff.

Year 2

In the first rainfall during the second year, compost not treated with alum had significantly higher SRP and total P concentrations in runoff water than plots treated with fresh poultry litter (Fig. 2a). Although not significant, alum-treated litter had lower P concentrations in runoff water than fresh poultry litter. Alum-treated compost reduced SRP concentrations in runoff water by 55% compared with normal compost. Total P concentrations from H_3PO_4–treated compost were significantly higher than all other fertilizer treatments.

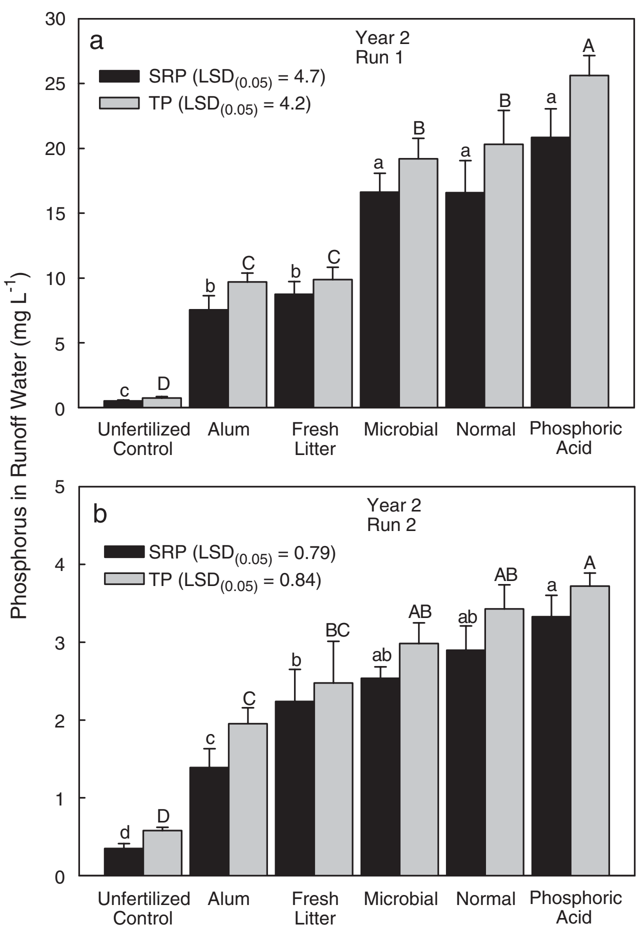

Fig. 2. Concentrations of SRP (soluble reactive P) and TP (total P) concentrations in runoff water from plots fertilized with fresh and composted poultry litter, with and without amendments, (a) 1 d after application and (b) 8 d after application in the second year of the study.

Phosphorus concentrations in runoff water were 47% lower from plots fertilized with fresh litter than those fertilized with normal compost (Fig. 2a). This is in contrast to the results of Vadas et al. (2004), who showed that composting reduced SRP concentrations in runoff from packed soil boxes by 60 to 80%. Sharpley and Moyer (2000) reported 42% less SRP leached from composted poultry manure than uncomposted manure. In these studies, however, the addition of C sources diluted the P concentrations in the starting compost mixture. For example, Vadas et al. (2004) reported that P concentrations of manures decreased by ~50% before composting due to dilution with low-P composting materials. As a result, P concentrations of the litter applied were much lower in the composted manure. Vervoort et al. (1998) reported greater P losses from fields treated with composted poultry litter than fresh poultry litter. They also concluded that composting created more stable P components and would reduce SRP concentrations in runoff water compared with fresh litter if each were applied at the same total P rate. In this study, however, P concentrations in runoff water tended to increase with increasing SRP application rates (Table 1 and Fig. 2a).

The second runoff study, conducted 1 wk after the first study, resulted in much lower concentrations from all fertilizer treatments. Soluble reactive P and TP concentrations from the unfertilized control plots were 0.35 and 0.58 mg L^{-1} (Fig. 2b). Soluble reactive P concentrations from plots fertilized with the alum-treated compost were significantly lower than all other fertilizer treatments. Amending litter with alum during the composting process resulted in a 52% reduction in SRP concentrations in runoff water compared with normal composted litter and a 38% reduction compared with fresh poultry litter. Although not significantly higher, the highest concentrations were from the H_3PO_4–treated compost.

Forage Yield

The amount of total N applied to plots cropped with tall fescue is given in Table 1. Total forage yields and total N uptake levels were significantly increased by all treatments over the unfertilized control (Table 2). Yields and N uptake showed the greatest response to fresh (uncomposted) poultry litter each year.

Yields were highest for plots fertilized with fresh litter, although they were not significantly higher than that observed for the alum-treated compost (Table 2). Fresh litter applications did result in significantly higher N uptake than all other treatments (Table 2). Although all compost treatments resulted in similar N application rates, significant differences were found among compost treatments for yields and N uptake. Compost treated with alum alone had significantly higher total yields and

Table 2. Forage yield and N uptake from small plots cropped with tall fescue in Year 1.

Treatment	First harvest	Second harvest	Third harvest	Total
	kg ha^{-1}			
	Forage yield			
Fresh litter	1233a	969a	394a	2596a
Alum	1095ab	924a	298b	2317ab
Alum + microbial	965abc	767b	269b	2001bc
H_3PO_4	839bcd	619c	230b	1688c
Microbial	879bcd	613c	227b	1719c
Normal	772cd	611c	241b	1624c
Unfertilized control	625d	324d	122c	1098d
LSD(0.05)	277	143	76	443
	N uptake by forage			
Fresh litter	42.3a	44.2a	40.1a	111a
Alum	38.4b	39.2b	35.1b	88.2b
Alum + microbial	37.8b	36.9bc	34.3bc	73.6bc
H_3PO_4	33.5c	35.8cd	32.8c	57.5c
Microbial	32.9c	35.2cd	33.5bc	56.8c
Normal	33.2c	35.2cd	33.5bc	56.8c
Unfertilized control	26.1d	29.5e	29.4d	30.1d
LSD(0.05)	3.76	2.91	2.34	19.2

N uptake levels than all compost not treated with alum. Compost treated with alum reduced NH_3 emissions during the composting process, resulting in more readily available N than other compost treatments and subsequently greater plant response (DeLaune et al., 2004b).

Greater plant response to fresh poultry litter may have been due to greater N mineralization rates for fresh poultry litter applications than the compost treatments. Several studies have shown higher N mineralization rates for fresh manures than composted manures (Hadas and Portnoy, 1994; Paul and Beauchamp, 1994; Hartz et al., 2000; Preusch et al., 2002). Compost acts as a slow-release fertilizer due to more stable N compounds; however, the mineralization and immobilization rates of composted manure vary and have yet to be well quantified (Chang and Janzen, 1996). Fresh poultry litter applications continued to result in significantly higher yields and N uptake for the third harvest, 6 wk after application, in Year 1 (Table 2).

Even though total N concentrations increased in compost treated with chemical amendments in Year 2, N application rates were higher with fresh poultry litter when all treatments were applied at equivalent application rates based on fresh weight (Table 1). In Year 2, fresh litter applications again resulted in the greatest plant response (Table 3). Yield data were affected due to crabgrass [*Digitaria ciliaris* (Retz.) Koeler] infestation on several plots. The first two harvests took place at the end of the growing season for crabgrass and crabgrass growth had subsided by the third harvest. Nevertheless, all treatments resulted in significantly higher total yields and total N uptake levels over the unfertilized control. Fresh litter applications had the highest total yields and highest N uptake levels for each individual harvest (Table 3).

Table 3. Forage yield and N uptake from small plots cropped with tall fescue in Year 2.

Treatment	First harvest	Second harvest	Third harvest	Total
	kg ha^{-1}			
	Forage yield			
Fresh litter	1995a	827a	395a	3216a
Alum	1495a	866a	380a	2741ab
H_3PO_4	1807a	788a	391a	2986ab
Microbial	1767a	705ab	352a	2824ab
Normal	1246ab	886a	337a	2469b
Unfertilized control	722b	449b	147b	1317c
LSD(0.05)	761	268	86	705
	N uptake by forage			
Fresh litter	73.4a	34.7a	16.5a	125a
Alum	57.2ab	33.7a	15.1a	106ab
H_3PO_4	66.8ab	31.6a	15.4a	114ab
Microbial	61.6ab	27.4a	13.8a	103ab
Normal	47.4b	34.2a	13.5a	95.2b
Unfertilized control	20.1c	13.2b	4.76b	38.1c
LSD(0.05)	25.3	11.0	3.49	24.7

CONCLUSIONS

Composted poultry litter without chemical amendments or bulking agents increased total P concentrations in the final compost mixture. Increased P concentrations due to retention along with loss of N during the composting process resulted in decreased N/P ratios. Soluble P concentrations were also elevated in compost without alum additions. Controlling soluble P levels seemed to be the most promising method to reduce runoff P, as the lowest runoff P concentration occurred from plots fertilized with the lowest amount of soluble P. Alum-treated compost increased N/SRP ratios and greatly reduced SRP and total P concentrations in runoff water. The composting process alone did not stabilize soluble P in poultry litter or runoff water. Plant response was greatest from plots receiving fresh poultry litter applications due to higher N availability. To supply equivalent N rates as fresh poultry litter, composted litter application rates must be elevated. Therefore, composting with chemical amendments such as alum may be necessary to limit soluble P levels in litter and surface runoff.

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